SAMPLE PROCESSOR FOR LIFE ON ICY WORLDS (SPLIce): DESIGN AND TEST RESULTS

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ABSTRACT

We report the design, development, and testing of the Sample Processor for Life on Icy Worlds (SPLIce) system, a microfluidic sample processor to enable autonomous detection of signatures of life and measurements of habitability parameters in Ocean Worlds. This monolithic fluid processing-and-handling system (mass ~ 0.5 kg) retrieves a 50-µL-volume sample and prepares it to supply a suite of detection instruments, each with unique preparation needs. SPLIce has potential applications in orbiter missions that sample ocean plumes, such as found in Saturn's icy moon Enceladus, or landed missions on the surface of icy satellites, such as Jupiter's moon Europa.

KEYWORDS: life detection; micro fluidics; icy worlds; ocean worlds; fluidic processor; sample processor

INTRODUCTION

Answering the question "Are we alone in the universe?" is captivating and exceptionally challenging. Even general criteria that define life very broadly include a significant role for water [1,2]. Searches for extinct or extant life therefore prioritize locations of abundant water whether in ancient (Mars), or present (Europa and Enceladus) times. Only two previous planetary missions had onboard fluid processing: the Viking Biology Experiments [3] and Phoenix's Wet Chemistry Laboratory (WCL) [4]. SPLIce differs crucially from those systems, including its capability to process and distribute µL-volume samples and the integration/autonomous control of a wide range of fluidic functions, including: 1) retrieval of fluid samples from an evacuated sample chamber; 2) onboard multi-year storage of dehydrated reagents; 3) integrated pressure, pH, and conductivity measurement; 4) filtration and retention of insoluble particles for microscopy; 5) dilution or vacuum-driven concentration of samples to accommodate instrument working ranges; 6) removal of gas bubbles from sample aliquots; 7) unidirectional flow (check valves); 8) active flow-path selection (solenoid-actuated valves); 9) metered pumping in 100 nL volume increments.

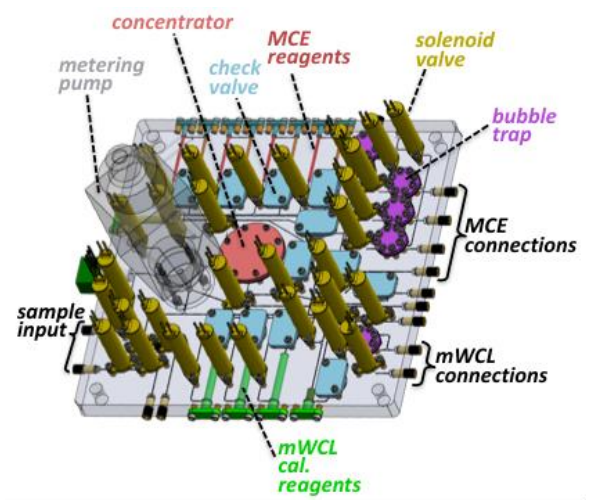

Figure 1. SPLIce block diagram with labeled components.

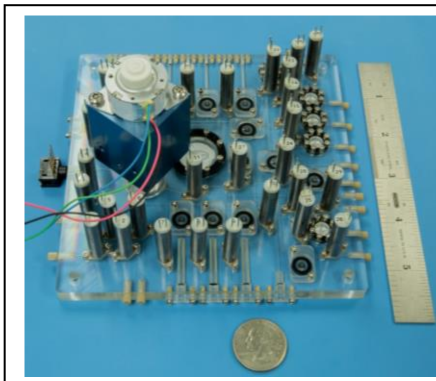

Figure 2. Photo of functional prototype 15.6 x 14.8 cm.

EXPERIMENTAL

The SPLIce manifold, made of three thermally fused layers of precision-machined cyclo-olefin polymer, supports all fluidic components (Figure 1 and 2) and integrated microchannels (125 x 250 µm). Fluid is pumped by a stepper-motor-driven pump (Lee Co.). The functionality of the integrated MEMS pressure sensor (Honeywell) and passive check valves (Figure 3) were tested in conjunction with our newly designed integral bubble traps (Figure 4) and a hydrophobic, PTFE membrane (0.2 µm pores)-based vacuum-driven concentrator (Figure 5.)

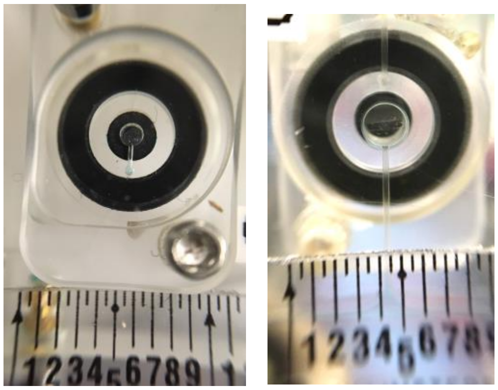
Figure 3. One-way check valve in custom mount (Outer diameter of cap seal = 11.4 mm). Top view (L); bottom view (R).

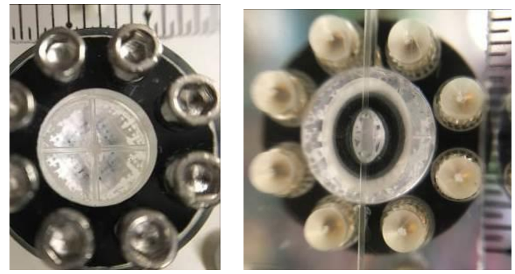
Figure 4. SPLIce bubble trap (OD of cap seal=13.8mm). Top view (L); bottom view (R).

RESULTS AND DISCUSSION

The integrated concentrator has demonstrated as much as 120-fold vacuum-evaporative concentration with an 8.4 mm^2 PTFE membrane surface area and 7.4 µL working volume. Polyethylene fused bead beds (PEFBBs; ~50% porosity) are used to store dry/lyophilized buffers, calibrants, and fluorescent dyes, and also to promote mixing of sample with calibrant, dye, or H_2O. Software-controlled automated tests demonstrated successful 1) fluid delivery to each component 2) valve and pump synchronization 3) sample aliquot delivery to instrument interface ports, and 4) rehydration of vacuum-dried fluorescent dye. In Figure 6, fluorescein on PEFBBs was rehydrated for 15 min using a pump-delivered water aliquot; it is displaced as H_2O enters the bottom of the channel and pushes the dye into a check valve.

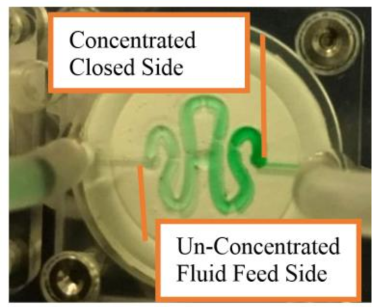

Figure 5. SPLIce vacuum-evaporation-based concentrator (inner diameter of cap seal = 14.1 mm).

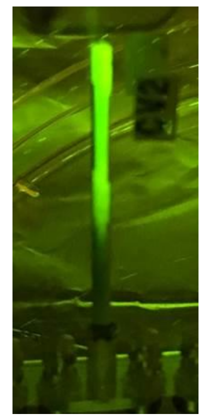
Figure 6. Rehydrated fluorescein dye is flushed from storage compartment (1.3 mm dia.) with the water entering from the bottom.

CONCLUSION

Ultimately, SPLIce will fluorescently label amino acids in the sample for microchip-based electrophoretic (MCE) chiral separation and detection to seek and quantify key organic biosignatures [5]; it will also deliver sample to a microfluidic WCL (“mWCL”) to measure soluble ions, pH, and redox-active species.

ACKNOWLEDGEMENTS

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Introduction

Sample Processor for Life on Icy Worlds (SPLIce) system: a microfluidic sample processor to enable autonomous detection of signatures of life and measurements of habitability parameters in Ocean Worlds.

- Monolithic fluid processing-and-handling system
- Prepares sample for a suite of detection instruments, each with unique preparation needs

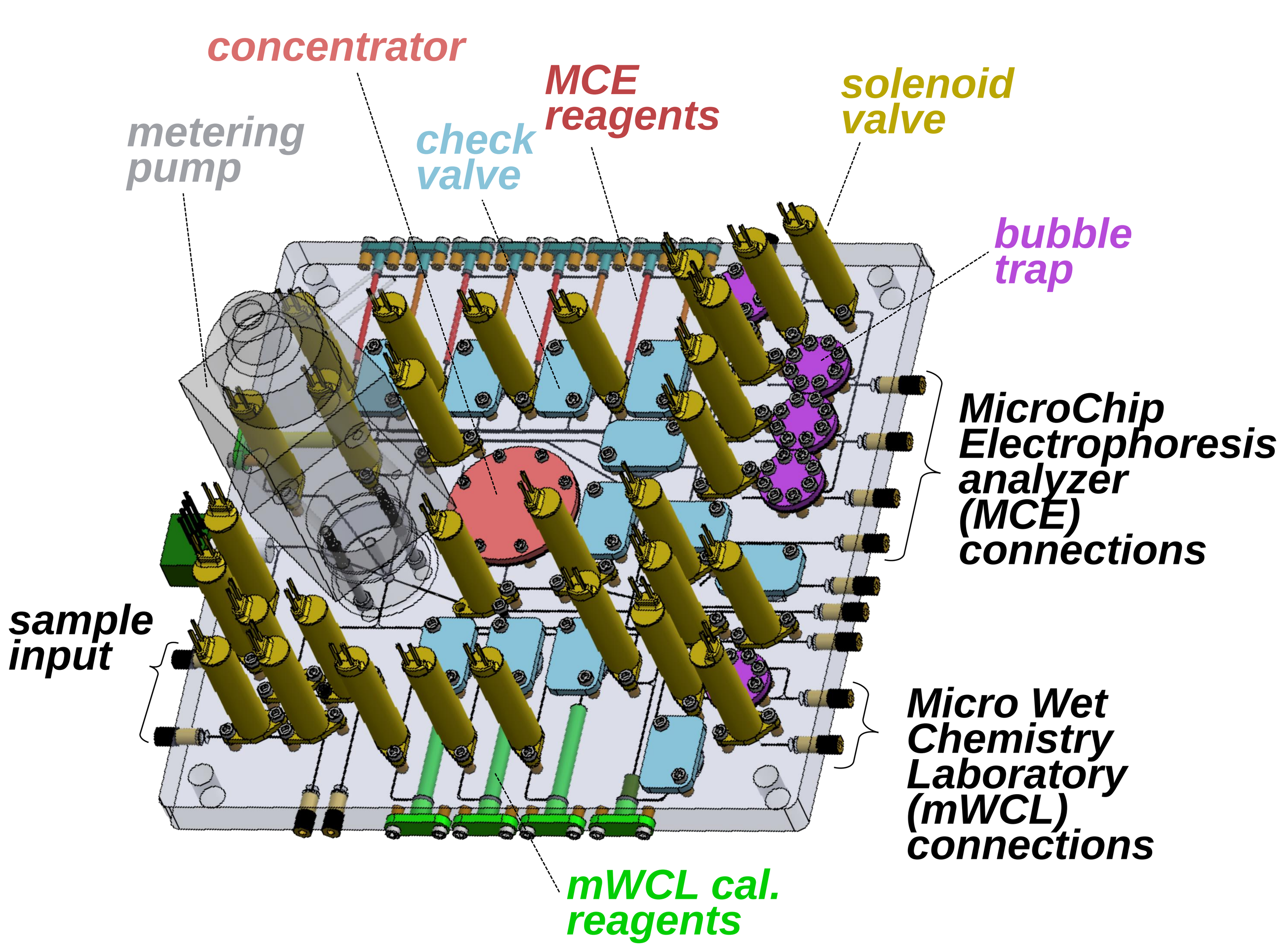
Potential applications:

- Orbiter missions that sample frozen plumes, such as found above Saturn's icy moon Enceladus
- Landed missions on the surface of icy satellites, such as Jupiter's moon Europa.

Fluidic System Overview

SPLIce differs crucially from previous onboard fluidic systems, including its capability to process and distribute µL-volume samples and the integration/autonomous control of a wide range of fluidic functions:

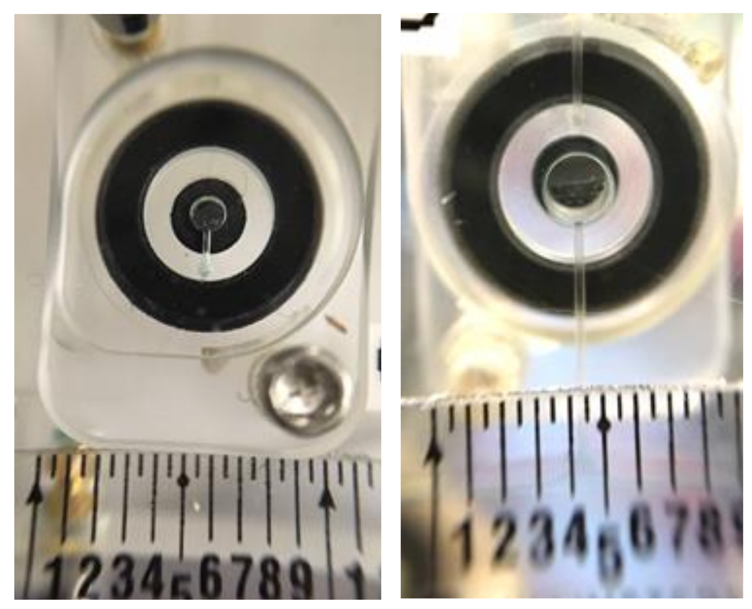
1. Retrieval of 50-µL fluid samples from an evacuated sample chamber
2. Onboard multi-year storage of dehydrated reagents
3. Integrated pressure, pH, and conductivity measurements
4. Filtration and retention of insoluble particles for microscopy
5. Dilution or vacuum-driven concentration of samples to accommodate instrument working ranges
6. Removal of gas bubbles from sample aliquots
7. Unidirectional flow (check valves)
8. Active flow-path selection (solenoid-actuated valves)
9. Metered pumping in 100 nL volume increments



Design and Fabrication

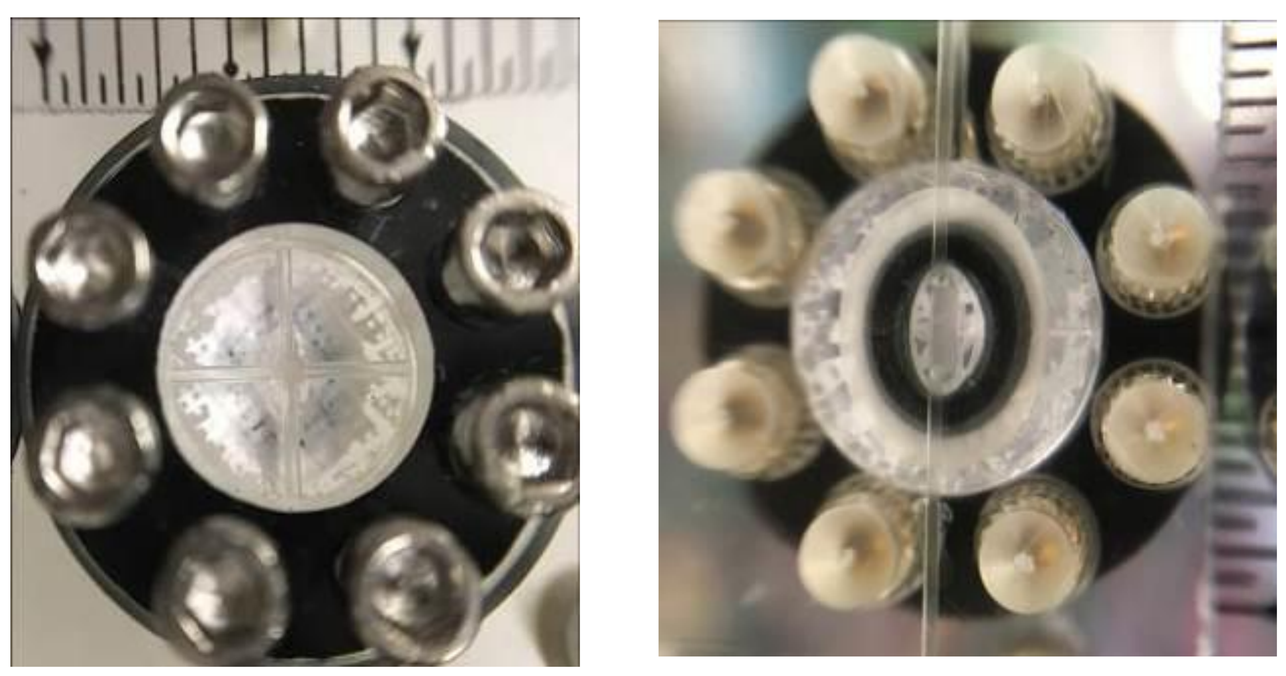
- Made of three thermally fused layers of precision-machined cyclo-olefin polymer, supports all fluidic components
- Integrated microchannels (125 x 250 µm)
- Fluid is pumped by a stepper-motor-driven pump (Lee Co.)
- The functionality of the integrated MEMS pressure sensor (Honeywell) and passive check valves were tested in conjunction with our newly designed bubble traps

Passive Check valve



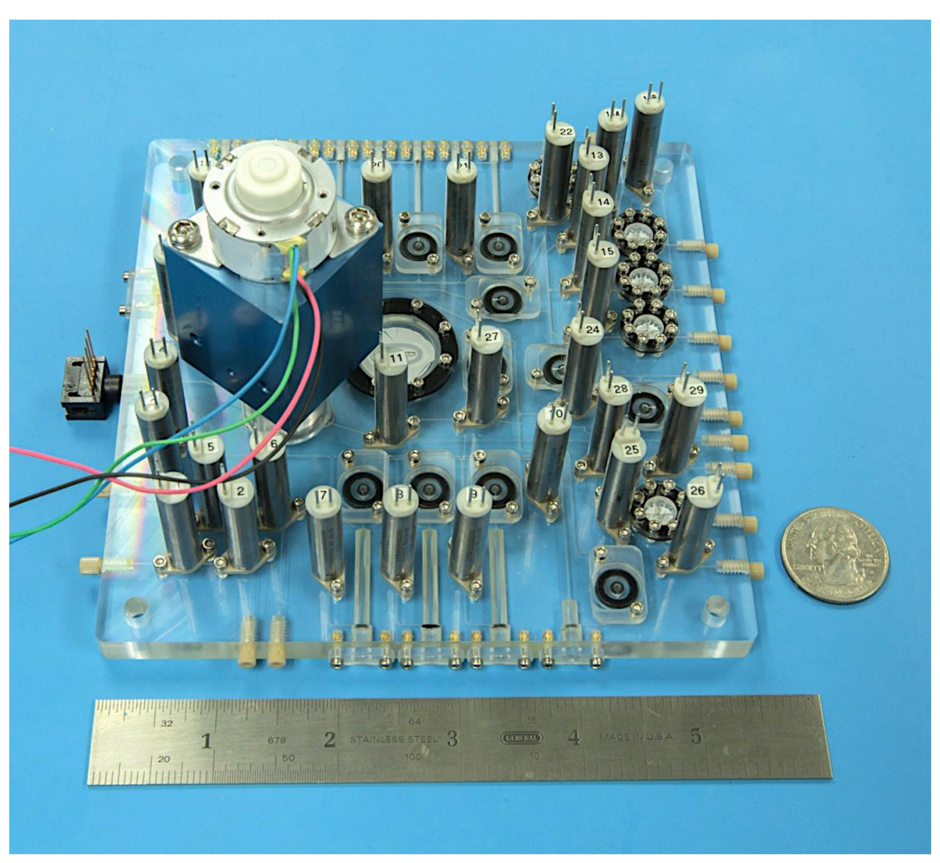
One way check valve, Top(L) and Bottom (R)

Bubble Trap



Integrated bubble trap (top view, L; bottom view, R) uses hydrophobic PTFE membrane to expel air

Fluidic Manifold

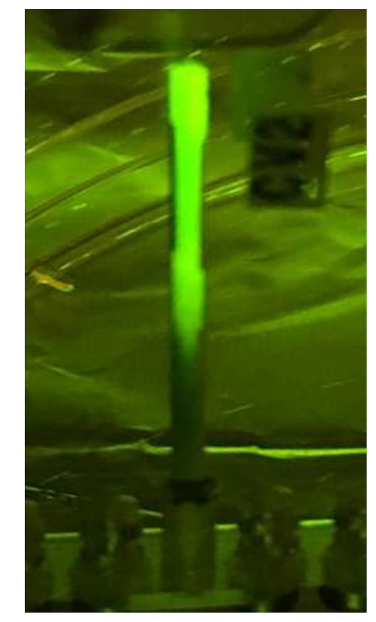


Manifold mass ~ 0.5 kg including all pictured components

Results

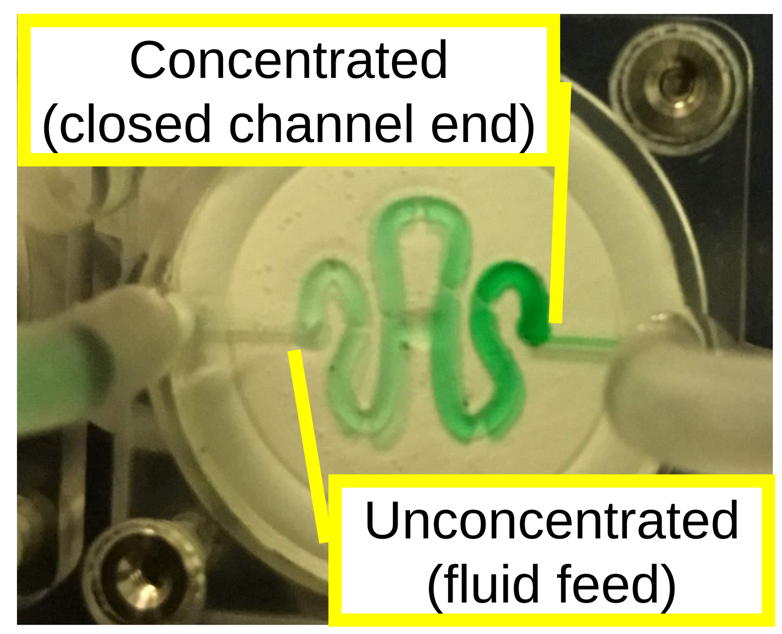
- Successful radiation tests of individual parts and reagents to ≥ 100 krad
- 120-fold vacuum-evaporative concentration
- Poly-ethylene fused bead beds (PEFBBs; ~50% porosity) used to:
  - Store dry/lyophilized buffers, calibrants, and fluorescent dyes
  - Promote mixing of sample with calibrant, dye, or H_2O
- Software-controlled automated tests demonstrated successful:
  1. Fluid delivery to each component
  2. Valve and pump synchronization
  3. Sample aliquot delivery to instrument interface ports
  4. Rehydration of vacuum-dried fluorescent dye

Dye Rehydration



Fluorescein on PEFBBs was rehydrated for 15 min using a pump-delivered water aliquot; it is displaced as H_2O enters the bottom of the channel and pushes the dye into a check valve

Integrated concentrator



8.4 mm^2 PTFE membrane surface area and 7.4 µL working volume

Conclusion

Ultimately, SPLIce will fluorescently label amino acids and amines for microchip-based electrophoretic (MCE) chiral separation and laser-induced-fluorescence detection to identify and quantify key organic biosignatures.

SPLIce will also deliver samples to a microfluidic wet chemistry laboratory (mWCL) to measure soluble ions, pH, and redox-active species to help assess the habitability of our solar system's icy worlds.

Acknowledgements

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